REVIEW ARTICLE

The Chemical Engineer's Perspective on the Role of the Central Nervous System (CNS) in Blood Pressure Control

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ABSTRACT: A comprehensive block diagram of the Blood Pressure Control (BPC) System of the body based on Control Engineering principles was designed through extensive research on the role of the CNS in BP control. The BPC system developed is the first to incorporate in one process system the three mechanisms of blood pressure regulation in the body. During the course of this research it was found that the CNS plays the role of a controller and achieves this by regulating the actions of the heart, blood volume and blood vessel diameter through the cardiac and vasomotor centers in the medulla oblongata of the brain. This regulation is carried out through Nervous stimulation via Parasympathetic and Sympathetic nerves of the cardiovascular system, and Hormonal stimulation via the Renin-Angiotensin-Aldosterone System (RAAS) and Adrenal gland. The Chemical Engineer's perspective in this role is based on principles of Control Engineering, Mathematical Modelling and Simulation. The Block diagram of the BPC System obtained shows that Process Control Engineering can indeed be applied in the study of the role the CNS plays in regulating the Blood Pressure (BP) system as well as other biological and physiological systems. The expertise of the Chemical Engineer is therefore very relevant in the biomedical field. The BPC system obtained in this study can be further developed through research and experimentation to obtain the system's mathematical model, subsequently simulate and create the software of the system for experimental variation of the parameters involved and possibly come up with novel solutions to BP related issues.

KEYWORDS: CNS, Role, Control System, Blood Pressure, Chemical Engineer, Process Control, Regulate, Perspective.

https://doi.org/10.29294/IJASE.9.3.2023.2949-2960 **©2023 Mahendrapublications.com, All rights reserved**

INTRODUCTION

Human beings are complex living organisms with different functional systems working in concert to ensure the state of steady Internal, Physical, and Chemical conditions (homeostasis) is maintained in the body [1]. The human body comprises ten systems, all of which work together for the wellbeing of the body. These systems are: digestive and excretory, endocrine, exocrine, immune and lymphatic, musculoskeletal, respiratory, renal, reproductive, cardiovascular, and the nervous systems. The cardiovascular system comprises of the heart and the circulatory system. It circulates blood around the body via the heart arteries and veins; the blood in circulation keeps the body temperature in a safe range, delivers oxygen and nutrients to organs and cells and carries waste products away [15]. The Nervous System consists of two main parts: the central nervous system (CNS) and the peripheral nervous system (PNS). It collects and processes information from the senses through the nerves and the brain. It coordinates and controls voluntary and involuntary actions and transmits signals between different parts of the body [1].

The Cardiovascular System is the transport system of the body. The heart, the blood vessels and the blood are the three main components that make up the transport system. The heart is a muscular organ that functions as an anatomical pump [2,5]. It is situated between the lungs, lying left of the center of the chest. The Heart is very similar to the dual diaphragm pump and is said to be one of nature's finest feats of engineering as it constantly pumps blood containing oxygen and nutrients to all parts of the body and receives it on return to transmit to the pulmonary circuit for gas exchange. This pumping process is powered by the special muscles of the heart and perfectly synchronized by electrical signals provided by a network of nerve tissue which runs through the

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Received: 18.11.2022 **Accepted:** 27.01.2023 **Published on**: 04.02.2023

heart conducting the complex signals that govern contraction and relaxation of the heart muscles. The Blood vessels are the channels or conduits through which blood is distributed to different parts of the body. Blood vessels are of three types: the arteries, the capillaries, and the veins. The size of blood vessel is different for each type. It ranges from a diameter of about 22 millimeters for the aorta to only 10 micrometers in the capillaries. The blood is a highly specialized tissue in fluid form. It contains dissolved oxygen and nutrients which it supplies all body cells and collects wastes to be removed from body cells. It is made up of several components, some of which are plasma, cells (RBC and WBC), and platelets. The Cardiovascular System performs many functions but this research focuses on how the CNS regulates the body's blood pressure.

Blood Pressure (BP) is the force exerted on the walls of blood vessels by the blood in circulation, resulting from the heart pumping blood through the Circulatory System. BP is an important vital sign used by healthcare professionals to evaluate the health of a patient. It is measured with a sphygmomanometer and is expressed in terms of the maximum pressure during one heartbeat (systolic pressure) over minimum pressure between two heartbeats (diastolic pressure) in the cardiac cycle [9]. BP is measured in millimetres of mercury (mmHg) above the surrounding atmospheric pressure. Normal BP ranges from $\frac{90\text{mm/Hg}}{60\text{mm/Hg}}$ to $\frac{120\text{mm/Hg}}{80\text{mm/Hg}}$. The human body requires a blood pressure high enough to supply organs with blood and nutrients needed to carry out metabolic activities, but not so high that blood vessels become damaged. The body must therefore maintain control over its blood pressure to keep it within a safe range [18].

The central nervous system (CNS) comprises of the Brain and the Spinal cord with brain as the central organ. The Spinal cord is the thoroughfare for communication between the body and the brain. The Spinal cord is a long, thin, tubular structure made up of nervous tissue, which extends from the medulla oblongata in the brainstem to the lumbar region of the vertebral column. The vertebral column contains the cerebrospinal fluid and encloses the central canal of the spinal cord [11,12].The human brain comprises of the cerebrum, the brainstem and the cerebellum. It is enclosed in, and protected by the skull bones of the head [13,14]. The brain is the control centre of the body. It controls all our voluntary and involuntary body functions and actions. Like a central computer, it processes and interprets information sent to it by nerves from our eyes (sight), ears (sound), nose (smell), tongue (taste), and skin (touch), as well as internal organs like the stomach and gives a feedback control decision or action. The CNS is a super complex system and in this research only its interaction with the cardiovascular system in regulating blood pressure is explored.

The Central Nervous System through the cardiovascular centre in the medullar oblongata of the brain plays the role of a control system in blood pressure regulation [16]. The cardiovascular centre in the brain achieves this by sending directly and through the spinal cord, signals that regulate the behaviour of organs and systems that influence the cardiovascular system and the cardiovascular system itself. The cardiovascular centre senses pressure through baroreceptors and responds to the degree of stretch caused by the presence of blood in the vessels. If there is a change in blood pressure, impulses are stimulated and sent to the cardiovascular centre for restoration of homeostasis by blood pressure regulation. The cardiovascular centre is made up of three components: the cardioaccelerator centre, the cardioinhibitor centre, and the vasomotor centre. These components have distinct roles: through the cardioaccelerator centre the CNS increases cardiac output by increasing heart rate and contractility. It achieves the opposite through the cardioinhibitor centre and through the vasomotor centre increases and reduces the diameter of blood vessels to regulate pressure. This mechanism is essentially the same as how a control system in chemical engineering works [3,14]. The principles of Chemical Engineering Process Control will therefore form the basis of this study.

To efficiently apply Engineering principles to proffer solutions to ailing human systems, these systems must be clearly understood by the Engineer [20,21].

Chemical Engineers consider the human systems and their fundamental physiology as a collection of networked processing units (reactors), assembled in form of a (chemical) plant [20]. In complex industrial plants or processes, the profitability, quantity and quality of the products, efficiency and optimal performance of the process, as well as the safety of the environment, would not be achieved

without the application of accurate automatic control of a number of variables. In a like manner, to maintain homeostasis in the human body, dozens of basic control processes are at work like the control of blood pressure, body temperature, blood-sugar level and level of hormones [27].

The ability to monitor and adjust a process to give or maintain a desired output is known as Process Control. When applied in chemical industries or processes it is known as Chemical Engineering Process Control. Irrespective of where Process Control is applied, process systems consist of three main variables: the manipulated variables, disturbances, and the controlled variables [3,24,25].The control of any industrial chemical process involves the monitoring of all the key variables and taking decisions and actions to keep the process operating optimally. The knowledge of Chemical Engineering Process Control can be explored and mapped onto physiological control of the human body systems in a quest to understand and develop novel processes, materials and tools for medical interventions to improve health and treat diseases.

2. METHODOLOGY

2.1.1. Process Control as it Relates to Blood Pressure

The study and application of automatic control in to maintain a process at the desired operating conditions, safely and efficiently, while satisfying environmental and product quality requirements is called Process control [24,25]. Just like a healthy cardiovascular centre in the human brain will keep the BP of the human person in a safe range for different human activities and enable the organs of the body function optimally, so does appropriate application of Process Control in the industry better the safety and effectiveness of a process. The autonomic control of the medulla oblongata where it regulates the heartbeat can be likened to artificial automatic control systems built to function without human input such as cruise control for regulating car speed. The practice of process control measures the output performance of the process being controlled via sensors and detectors; these measurements are used to provide remedial feedback to help to achieve the desired performance [18]. Similarly, the process of BP regulation utilizes baroreceptors and chemoreceptors to gauge output performance of the cardiovascular system; the gauged outputs are used to provide feedback to the CNS to help maintain the desired BP range [27,28].Due to the value of human life, researchers cannot apply the "trial-and-error" method directly on an actual living person. Instead, human biological processes are modelled as a set of mathematical equations in advance. Applying the practice of process control to blood pressure regulation and medicine in general creates a means for worriless experimentation on operating procedures and optimization strategies. Through this process researchers can observe in a few minutes the effects of a broad range of events and perform efficient testing of the control systems configuration prior to implementation.

2.1.2. BP Control from the Process Control Perspective

Human body systems function to achieve desirable conditions. The need to effectively sustain nutrient and oxygen supply to satisfy all tissues' requirements isessential and wholly dependent on healthy level stabilization of blood pressure. It is also very central to achieving homeostasis in the body. Most control systems in the body work in a closednegative feedback control loop [29]. Appling Process Control analysis to Blood Pressure Control:

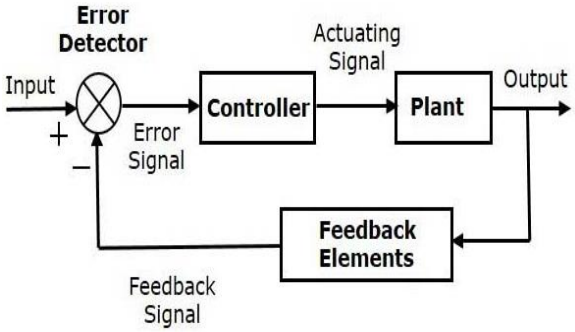


Figure 2a: Block diagram of process control system Error! Reference source not found.

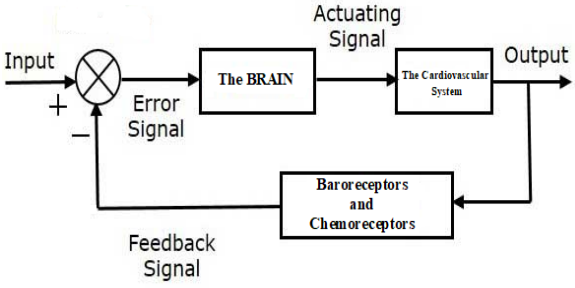


Figure 2b: Block diagram of applied Process Control analysis to Blood Pressure Control

2.2.1. Determination of Block Diagram of the Body's General Control System

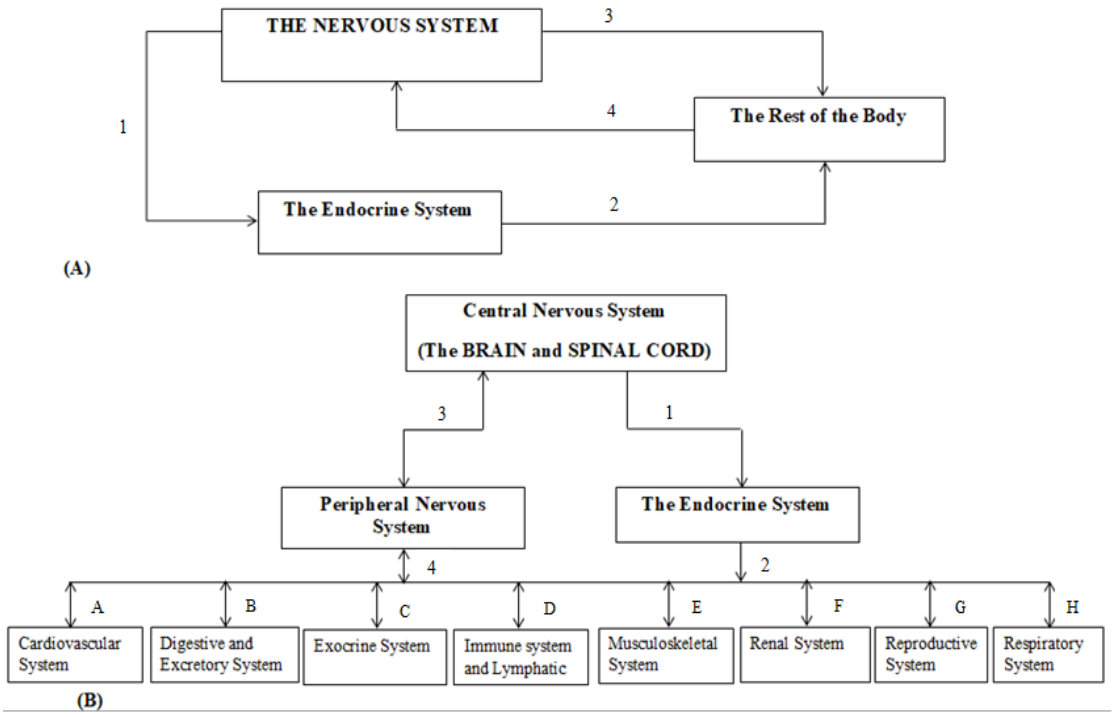


Figure 2.1: Block Diagram of the Body's General Control System

The Nervous System is charged with the responsibility of maintaining homeostasis in the body, this it does by coordinating the nerves and the endocrine system (Figure: 2.1A). The coordination is achieved by sending control signals through efferent nerves (Stream 1, figure 2.1A) to the endocrine system to release specific enzymes depending on the requirement of the body. The released enzymes (Stream 2, Figure 2.1A) are carried in circulation to the specific parts or organs of the body that require them. For homeostasis to continue to be maintained, control signals are also sent directly from the Nervous System to the body (Stream 3, Figure 2.1A). The nervous system monitors the body's requirements through (Stream 4, Figure 2.1A) the feedback signal from the body to the Nervous System.

The Central Nervous System is charged with the responsibility of being the Processing Unit of the Nervous system. Figure 2.1B to shows how the CNS maintains homeostasis in the different body systems. Information signals are sent out through efferent nerves (Stream 1, Figure 2.1B) from the Central Nervous System to the Endocrine System. The released enzymes (Stream 2, Figure 2.1B) are carried in circulation to the specific body systems that require them. Stream 2A shows the flow of released enzymes that influence the Cardiovascular System. Stream 2B shows the flow of released enzymes that influence the Digestive and Excretory systems. Stream 2C shows the flow of released enzymes that influence the exocrine system. Stream 2D shows the flow of released enzymes that influence the Immune and Lymphatic system. Stream 2E shows the flow of released enzymes that influence the Musculoskeletal system. Stream 2F shows the flow of released enzymes that influence the Renal System. Stream 2G shows the flow of released enzymes that influence the Reproductive system. Stream 2H shows the flow of released enzymes that influence the Respiratory system.

The efferent nerves (feed-forward) and afferent nerves (feedback) send signals between the Central Nervous System and Peripheral Nervous System (See Stream 3, Figure 2.1B). Stream 4, figure 2.1B shows the feed forward and feedback signals between the Peripheral Nervous System and the body systems. Stream 4A shows the feed forward and feedback signals between the Peripheral Nervous System and the Cardiovascular System. Stream 4B shows the feed forward and feedback signals between the

Peripheral Nervous System and the Digestive and Excretory system. Stream 4C shows the feed forward and feedback signals between the Peripheral Nervous System and the Exocrine system. Stream 4D shows the feed forward and feedback signals between the Peripheral Nervous System and the Immune and Lymphatic system. Stream 4E shows the feed forward and feedback signals between the Peripheral Nervous System and the Musculoskeletal System. Stream 4F shows the feed forward and feedback signals between the Peripheral Nervous System and the Renal System. Stream 4G shows the feed forward and feedback signals between the Peripheral Nervous System and the Reproductive system. Stream 4H shows the feed forward and feedback signals between the Peripheral Nervous System and the Respiratory system.

2.2.2. Determination of Block Diagram of Cardiovascular Control System

The cardiovascular system is charged with the responsibility of regulating the body's blood pressure within safe limits (homeostasis)[31-33]. It achieves this by responding to signals from the CNS and utilizing its intrinsic Cardiac Control System (See Figure 2.2).

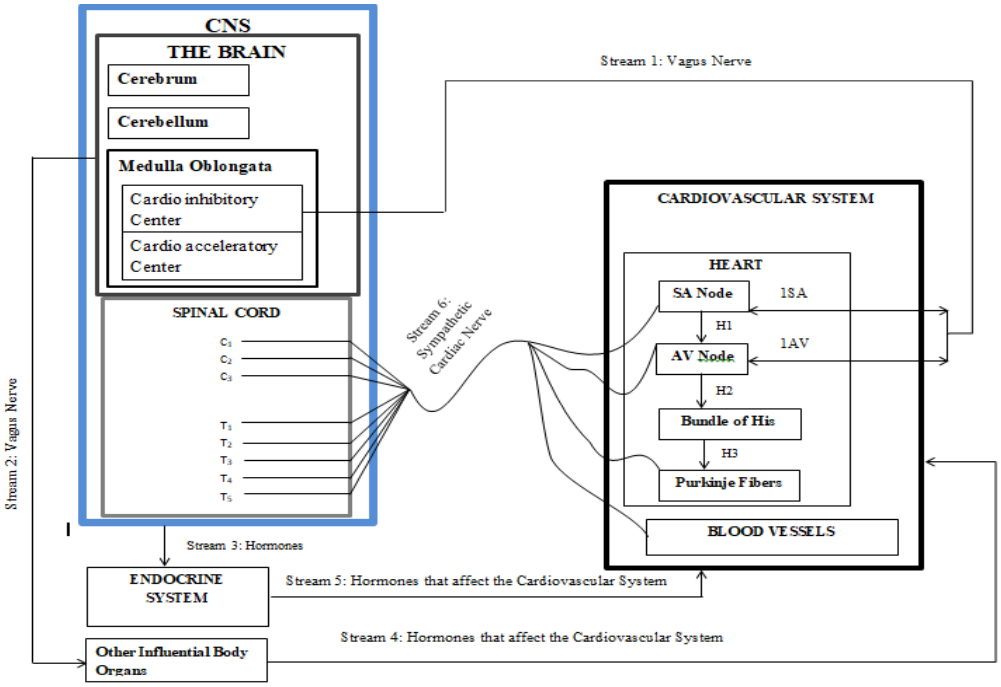
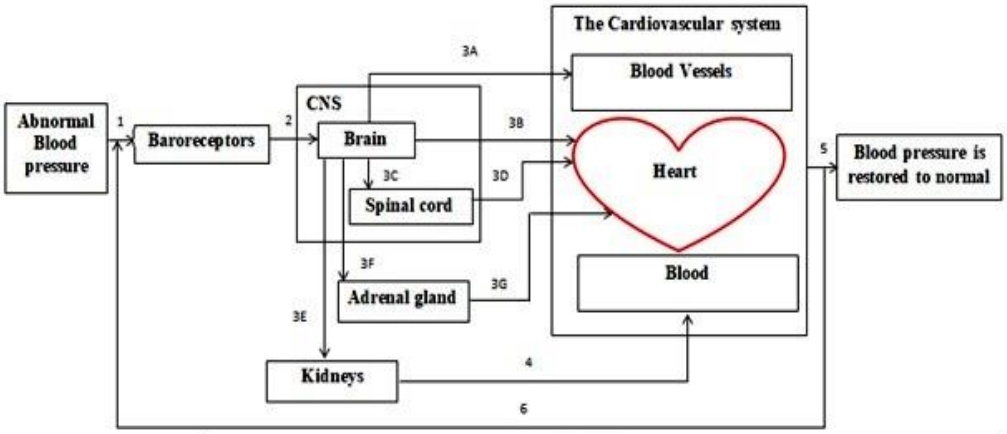


Figure 2.2: Block Diagram of the Cardiovascular Control System

Stream 1SA depicts the flow of feed-forward and feedback signals through the Vagus Nerve from the brain to the SA node. Stream 1AV shows the flow of feed-forward and feedback signals through the Vagus Nerve from the brain to the AV node. Stream 2 shows the flow of control signals through the Vagus Nerve from the brain to organs that influence the Cardiovascular System. Stream 3 shows the flow of released hormones that influence the endocrine system from the pituitary gland in the brain. Stream 4 shows the flow of released hormones from organs that influence the Cardiovascular System. Stream 5 shows the flow of released hormones from the endocrine system to the Cardiovascular System. Stream 6 depicts the flow of feed-forward and feedback signals between the Cardiovascular System and the spinal cord. Stream H1 shows the flow of control signals from the SA node to the AV node. Stream H2 shows the transmission of control signals from the AV node to the bundle of His. Stream H3 shows the flow of control signals from the bundle of His to the Purkinje fibres. The Purkinje fibres transmit to the heart muscles to enable contraction.

2.2.3 Determination of Block Diagram of Blood Pressure Control System

Figure 2.3 is extracted from the expanded block diagram of the Cardiovascular Control System in Figure 2.2. It shows Brain control of the Cardiovascular System in regulating blood pressure. The baroreceptors are responsible for relaying impulses to the cardiovascular center in the brain.



Legend		
Flow lines	When Blood Pressure is increased	When Blood Pressure is reduced
1	Blood Pressure	Blood Pressure
2	Increased Blood Pressure	Reduced Blood Pressure
3A	Vasodilation	Vasoconstriction
3B	Vagal reduction of cardiac output, heart rate and Heart contractility.	Vagal effect inhibited
3C	Inhibition of Sympathetic Nervous Activity.	Stimulation of Sympathetic Nervous Activity.
3D	Sympathetic Nervous Activity not transmitted	Increase cardiac output, heart rate and Heart contractility.
3E	Inhibit RAAS process to reduce Extracellular Volume	Initiate RAAS process to Increase Extracellular Volume
3F	Inactive.	Activation of fight or flight response.
3G	No activity	Adrenal increase in cardiac output, heart rate and Heart contractility.
4	Reduction of Blood Volume	Increased Blood Volume
5	Normalized Blood Pressure.	Normalized Blood Pressure
6	Feedback Blood Pressure	Feedback Blood Pressure

Figure 2.3: Block Diagram of Blood Pressure Control System (BPC System)

Stream 1 shows the conduction of the degree of stretch of blood vessel walls due to blood flow to the baroreceptors. Stream 2 shows the transmission of impulses generated by the degree of stretch of the blood vessels walls from the baroreceptors to the brain. Stream 3A shows the flow of signals from the brain through sympathetic and parasympathetic nerves to the blood vessel to constrict and dilate respectively. Stream 3B shows the flow of parasympathetic signals from the brain through Vagus nerve to the SA node of the heart. 3C shows the flow of signals from the cardiac center in the brain to the cervical and thoracic segments of Spinal cord. Stream 3D shows flow of sympathetic signals from the cardiac nerves of the spinal cord to the Heart. Stream 3E shows flow of signals from the brain through the sympathetic and parasympathetic nerves and hormonal signals from the pituitary gland in the brain to the kidneys. Stream 3F shows flow of signals from the brain through adrenal sympathetic nerves and hormonal signals from the pituitary gland in the brain to the adrenal gland. Stream 3G shows flow of signals from the adrenal gland to the Heart to increase cardiac output, heart rate and heart contractility. Streams 3f and 3G occur only in fight or flight mode. Stream 4 shows the RAAS process which increases or reduces blood volume. Stream 5 shows blood flow of normalized pressure. Stream 6 shows flow of feedback signals by the baroreceptors.

2.2.4 Expressing BPC Block diagram in Control loop form

To properly visualize and apply Control Engineering, the BPC block diagram is expressed in a control loop form as shown in Figures 2.4 to 2.7. The control objective is to maintain and regulate the body's BP as required by the metabolic activities of the body. The design inculcates both short and long term BPC. The short term BP regulation and control systems are shown in figures 2.5 and figures 2.6, while the long term is shown in figure 2.7.

2.2.5 Short term Nervous BPC Block Diagram

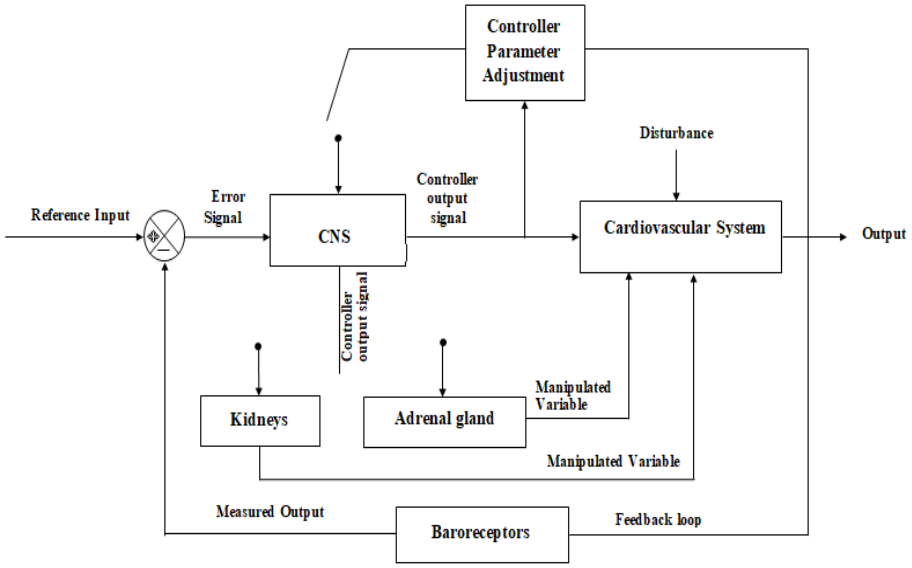


Figure 2.4: depicts the block diagram of short term BPC through the sympathetic and parasympathetic nerves.

Figure 2.4 depicts the block diagram of short term BPC through the sympathetic and parasympathetic nerves. The most important feature of the nervous system control of blood pressure is the speed of response, where significant changes in blood pressure levels can be achieved within seconds. It is the first response by the CNS to control blood pressure. The Reference input or the set point is the Mean Arterial Pressure (MAP) range of a healthy human which is 70mmHg – 100mmHg, but varies depending on the state of the body. The measured output is the feedback signal transmitted from the baroreceptors. The baroreceptors are the sensors. The output is the controlled BP which is the process variable. The Error signal is the difference between the measured output and the set point. The CNS is the controller while the controller output is the signal which manipulates some variables in the cardiovascular system to stabilize blood pressure for short term control. Disturbances to the system could be exercise, low blood pressure and high blood pressure, etc. The Cardiovascular System is the process, while the Kidneys and Adrenal gland are control elements for long and short term control respectively. The manipulated variables are blood volume, heart contractility, cardiac output (heart rate and stroke volume product) and blood vessel diameter.

2.2.6 Long term BPC Block Diagram Design

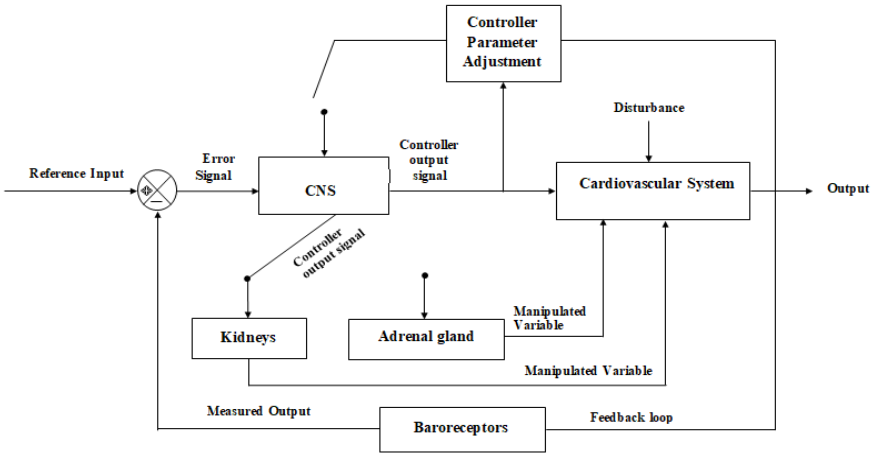


Figure 2.5: Long term BPC Block Diagram

The block diagram designed for long term BPC is shown in Figure 2.5. The control objective is to maintain and regulate the body's BP as required by the metabolic activities of the body over a period of hours or days. It is considered the most powerful blood pressure control mechanism in the human body. The Reference input (set point), the measured output (feedback signal), the baroreceptors (sensors), the output (controlled BP or process variable), the Error signal (difference between the measured output and the set point), and the CNS (controller), the Cardiovascular System (the process), Kidneys (control elements) are as described in Figure 2.4.

The controller output is the signal which manipulates some variables in the Cardiovascular System as well as stimulates the kidneys to start or stop variation NaCl and water content of the blood through the RAAS process for long term BP control. Disturbances to this system could be high salt diet, low blood pressure or high blood pressure. The manipulated variable is the blood volume.

2.2.7 Block Diagram Design of BPC during Fight or Flight Mode

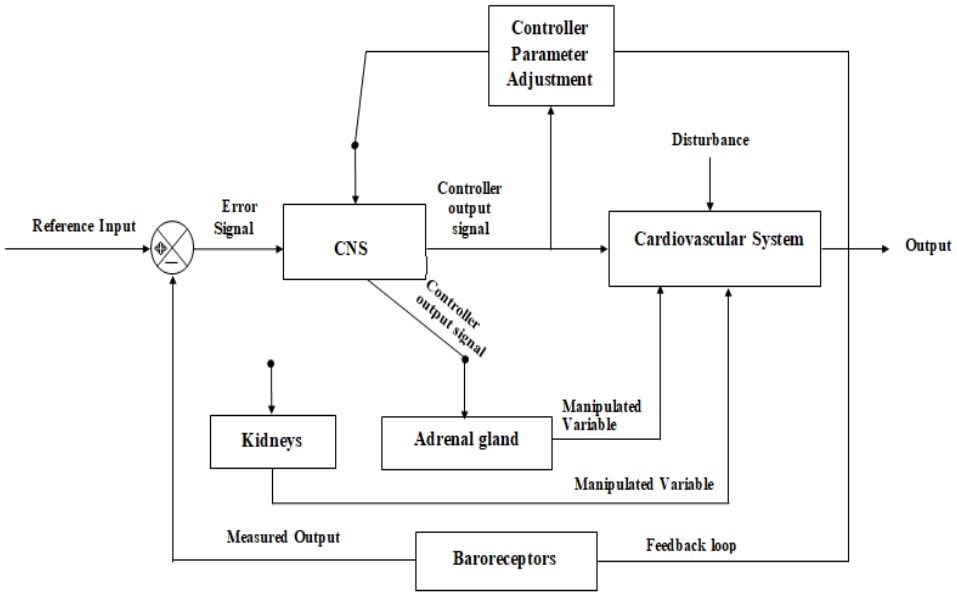


Figure 2.6: Block Diagram Design of BPC during Fight or Flight Mode

Figure 2.6 shows the block diagram design of BPC during fight or flight mode. The control objective is to maintain and regulate the body's BP during dangerous, anxious, stressful and fearful situations. This mode is active until the threat or cause of the situation has passed, then the effect of its activation fades off within 20 minutes. The set point is automatically re-set as required by the brain in the CNS through the controller parameter adjustment to suit the fight or flight mode requirement. The measured output (feedback signal), the baroreceptors (sensors), the output (controlled BP or process variable), the Error signal (difference between the measured output and the set point), and the CNS (controller), the Cardiovascular System (the process), Kidneys (control elements) are as described in Figure 3.4. The disturbance is the reason fight or flight mode was activated. The manipulated variables are cardiac output, heart contractility and blood vessel diameter. The feedback from the baroreceptors is compared with the output of the internal model to implement model-reference control .

3.2 RESULTS AND DISCUSSION

The result from the application of Process Control principles to analyze Blood Pressure Control is depicted in Figure 3.7.The designed Block diagram of the Blood Pressure System of the body is a Single input Single output closed loop System. The nervous blood pressure control though short term is always connected for monitoring and maintenance. The set point of the system is the Mean Arterial Pressure of a healthy human which falls within the range of (70-100) mmHg. The process flow of the nervous control starts with the generation of the error signal in the summing point by comparing the set point in the cardiac centre

which is in the medulla oblongata of the brain in the CNS (G_c) to the output of the blood pressure system transmitted by the baroreceptors. If blood pressure is low, the error signal is then transmitted through the spinal cord out of the G_c then through the cardiac sympathetic nerves to the cardiovascular system (G_p). This stimulation increases blood pressure by manipulating cardiac output through increment in heart rate (number of times the heart beats per minute) and increment in heart contractility (force of contraction of the heart). It also simultaneously manipulates blood vessel diameter by increasing the Total Peripheral Resistance-TPR of blood vessels (increasing resistance to blood flow) and increasing venous return through vasoconstriction, hence increasing blood pressure. The stimulation of the cardiac sympathetic nerves stops once blood pressure is restored to normal. If blood pressure is high the error signal is transmitted through the Vagus nerve which produces parasympathetic stimulation. Parasympathetic excitement of the G_p from the G_c through the Vagus nerve reduces blood pressure by manipulating cardiac output through decrease in heart rate and heart contractility resulting in a decrease in blood pressure. Once blood pressure is restored to normal, the stimulation of the Vagus nerve stops. The short term blood pressure control is the mechanism used by the body to regulate blood pressure in our day to day activities.

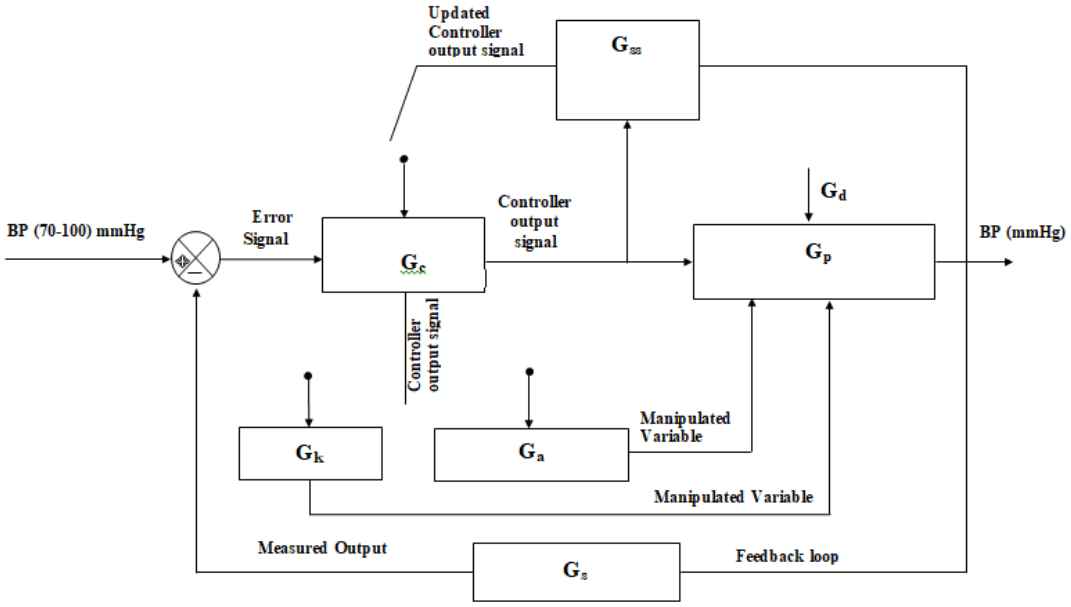


Figure 3.7: Block diagram of Blood Pressure Control System of the body.

The G_c activates the RAAS process which is the long term BP control mechanism, if the blood pressure after a certain amount of time has not been regulated appropriately by the short term nervous blood pressure control. In this design, the activation is represented by a relay connection of the output signal from the G_c to the G_k (Kidneys). When blood pressure is low, this signal activates the RAAS process by manipulating the blood volume by increasing extra cellular fluid (ECF) through reabsorption of Sodium and water. This stimulation also manipulates the blood vessel diameter by increasing the Total Peripheral Resistance-TPR of blood vessels (vasoconstriction). The heart muscles are stretched due to the increased ECF resulting in increase inblood pressure with each beat. The circulating blood volume is directly proportional to the stretch of the heart muscles.

In fight or fight mode, the G_{ss}activates the fight or flight blood pressure control process by the connecting the relay between the $G_c$and the Controller Parameter Adjustment (G_{ss}). The connection immediately stimulates the connection of the second relay between the G_c and the adrenal gland. The adrenal gland then releases hormones that increase blood pressure. The control loop for the fight or flight BPC system operates like a scheduled adaptive control scheme in which, as a result of previous process knowledge of the cause of fight or flight mode and easy quantification of what is responsible for the change, the commensurate change required in the G_{ss} are scheduled ahead of time. Significant change in the input and

output variables of the process are sent to the G_c, and parameters of these variables are adjusted according to the pre-programmed G_{ss} schedule. For example, for a person who is in danger, the forebrain (G_{ss}) in the CNS analyses the situation and from memory (previous experience) decides the situation is dangerous, it then sends a signal immediately to the cardiac centre (G_c) to adjust the set point of the BP to one high enough to propel the person out of the dangerous situation. The G_c transmits this new error signal to the G_p and the BP is maintained at the new set point until the threat of danger has passed. This signaling is discontinued after the danger threat is over.

The block diagram of the Blood Pressure System of the body obtained shows that Process Control can indeed be applied in the study of role the CNS plays in regulating blood pressure as well as other biological and physiological systems. The expertise of Chemical Engineers is therefore very relevant in the biomedical field. The BPC system can be further developed through research to obtain mathematical models for each of the individual elements of the system. This would go a long way in eliminating the problem of experimenting directly on humans and create room for better understanding of the blood pressure system. The development of the system can be taken a step further by simulating the mathematical model which would create a platform for experimental variation of the parameters involved and produce novel solutions to Blood Pressure related issues.

CONCLUSION

From the research carried out, the conclusions below can be drawn:

- The role of the CNS in Blood Pressure Control and Regulation is that of a controller.
- The Chemical Engineer's perspective on this role is based on the principles of Control Engineering. The expertise of a Chemical Engineer can therefore be applied through the knowledge of Control Engineering, Mathematical Modelling and Simulation.
- The CNS controls BP through regulation of the actions of the heart, regulation of blood volume and the control of the constriction and dilation of the blood vessels. This regulation is achieved through the cardiovascular centre and the vasomotor centre in the medulla.
- The regulation of BP is carried out through
  - Nervous stimulation via Parasympathetic and Sympathetic nerves of the cardiovascular system.
  - Hormonal stimulation via the Renin-Angiotensin-Aldosterone System (RAAS) and the Adrenal gland.

The BPC system developed is the first to incorporate in one process system the three mechanisms of blood pressure regulation in the body.

It is disturbing that over 7.6 million people die from raised Blood Pressure (BP) annually and the lack of interdisciplinary research in BP control especially in the field of Engineering has created paucity of information in the area [12]. Consequently, raised BP and complications of it have continued to be the leading cause of death in adults.

To find solutions to abnormal blood pressure and its complications the BPC System should be modelled and simulated. To achieve this, a relationship between input and output must be found for each component of the BPC System developed. This relationship is a mathematical function which theoretically models the component's output for each possible input See Figure 4.1. Mathematical models for each component has to be derived empirically (from experimental data) or physically (where knowledge of system characteristics are used to derive equations). Unfortunately there is no available data to model the obtained BPC system block diagram and so the mathematical model and simulation cannot be derived empirically. The unavailability of empirical data shows that exact characteristics of the system is not known therefore physical modelling of the system is also not yet possible. A system without mathematical representation or model cannot be simulated.

From the research carried out, the following suggestions are therefore recommended:

- Efforts should be made towards inter-coupling of biological sciences with engineering to improve and increase innovations in medical care. Special attention should be paid to interdisciplinary research, especially in Chemical Engineering field to bridge information lack in the area.
- Experimental research should be carried out on lab animals like rats and rabbits to generate data to mathematically model each component of the BPC system designed.

The development of the BPC system should be taken a step further by simulating the mathematical model as this will help eliminate the problem of experimenting directly on humans as well as create room for better understanding of the blood pressure system of the body. The simulation would also produce a platform for experimental variation of the parameters involved in the design of the system; provide insight to BP related issues and create possible solutions.

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